<u>**HEALTH AND SAFETY REPORT**</u>
of the
Health and Safety Subcommittee
Committee for Renewable Energy for Barrington
Barrington, RI
August 15, 2008

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Summary:

The goal of this report is to summarize information on health and safety concerns related to the proposed construction and operation of a wind turbine in Barrington. Pursuant to the committee's own search for information and that of other concerned citizens, the Health and Safety Subcommittee identified the most important issues to be noise, structural failure, icing, shadow flicker, and wildlife impacts. This report reflects the best efforts of the subcommittee to develop an informational document on health and safety concerns in a relatively short time frame for the benefit of the entire community. Readers should keep in mind the positive benefits of renewable energy, including reduction of the 106 premature deaths per year ascribed to emissions from the Brayton Point power plant in Somerset, MA, and displacement of 6,900 tons of carbon dioxide emissions per year from conventional electricity generation.

<u>Structural Failure</u>

- Although wind-turbine structural failures have occurred, most commonly in the form of blade failures, to date all but one of the documented injuries from wind turbines have been associated with accidents involving wind industry workers and not structural failure. Incidence of accidents is rising as the number of turbines in service increases. Attention to safety in transport, installation, and maintenance is essential in reducing the risk of injury.
- The worldwide incidence of structural failures is about 420 per million turbine years. This means that each turbine has a risk of blade or other failure of about 1 in 2400 in a given year. The probability of failure of a new turbine can be lowered by dealing with reliable manufacturers and contractors and following good maintenance and operational practices.
- The probability of injury is determined by the probability of failure, combined with the probability that a blade fragment lands in an area where people are present. Based on a nationally accepted approach, it is estimated that a person who remains all year long at a distance of just under 900 ft from the turbine has a probability of being hit by a blade tip fragment of about 4 in 10 million, roughly the same as being hit by lightning. A person who remains all year long at a distance of just under 450 ft has a probability of being hit by a whole blade of about 1.3 in 1 million, about half the chance of being electrocuted in a year.
- A 900 ft setback would essentially eliminate the chance of injury due to structural failure. Prescribed setbacks for structural safety are typically 1,000 ft from the nearest dwelling,

within the distance to dwellings at the Legion Way site but larger than the 190 ft at the high school site.

Noise

- A sound pressure level of 60 decibels (dB) is typical of ordinary conversation in a living room, 40 dB a soft whisper 6 ft away in a library, and 20 dB that inside an unoccupied soundproof studio.
- Noise issues can be of serious concern for some people who live near turbines. The significance of problems varies with size and number of turbines, distance from the turbine, and the terrain between turbine and receiver. Noise disturbance is subjective, and sources differ on the severity of the problem. Turbine noise is more audible at night than in daytime, especially on calm, clear nights when wind at ground level is insignificant but the wind at turbine height can still drive the turbine.
- Infrasound is sound below the limits of human hearing. Wind turbines produce infrasound but do so at levels below 90 dB, the detectable level below which there is no evidence of adverse effects. Low-frequency loudness variations, a "swish-swish" sound, increase the annoyance of turbine noise, an effect not taken into account by overall average dB levels.
- Noise restrictions are 49-67 dB for U.S. federal agencies, and 35-45 dB at night in Europe. Massachusetts and Oregon limit new broadband (atonal) sounds to 10 dB above ambient. The World Health Organization (WHO) sets limits of 55 dB outside during the day, 45 dB outside at night, and 30 dB indoors at night for sleeping. The American National Standards Institute (ANSI) limits indoor background noises to 35 dB in classrooms.
- At the Barrington High School site, a wind turbine is estimated to produce outdoor noise of 53 dB at the high school itself and 47 dB at the nearest dwelling. These levels are below the WHO daytime standard at the high school but above the WHO nighttime standard at the nearest dwelling. Interior noise either inside dwellings or in the high school itself is estimated to be well below WHO and ANSI standards only with windows closed.
- At Legion Way, outdoor noise at the nearest home is estimated to be 41 dB, resulting in sound levels that are within WHO standards both during the day and at night, outdoors and indoors, even with windows open.
- A noise limit of 42 dB, which accounts for various conditions including low frequency "swishing" sounds, is satisfied at distances of 900 ft or greater from the proposed Barrington turbine.

Icing

- Icing on wind turbines occurs under the same wintry conditions as icing on other structures or plants. Ice fragments thrown from wind turbines have been reported as being typically up to 2 lbs and generally landing within 330 ft of wind turbines.
- Industry rules-of-thumb for icing are based on tower height and turbine diameter and range between 620 and 730 feet for the proposed Barrington turbine. These setbacks are greater than virtually all reports of distances of ice fragments thrown or falling from turbines.

Shadow Flicker and Lighting Effects

- Shadow flicker from wind farms has been documented to cause annoyance and health effects, and flicker from a single turbine can affect drivers. Flicker from wind turbines is too slow to cause epileptic seizures.
- Shadow flicker depends on alignment of receiver, sun, and turbine; wind and solar conditions; distance from the turbine; time of day; and time of year. A commonly used limit for acceptable exposure to shadow flicker is 30 hours per year.
- At the Barrington High School site, cars and a few houses on County Road, Federal Road, and Upland Way would be likely to experience substantial flicker for less than 20 minutes per day for about one month a year. This would occur only on sunny days when the turbine is operating and is oriented in particular directions.
- At the Legion Way site, houses along Middle Highway would be exposed to flicker in the mornings, but the exposure is estimated to be less than 12 hours per year and less than 20 minutes per day.
- Flicker effects can be ameliorated through control strategies such as evergreen tree plantings. FAA lighting requirements should be met so as to control effects at ground level.

Wildlife Impacts

- Based on studies conducted at wind farms in Tennessee and West Virginia, bird mortality in the eastern U.S. averaged about 4 birds per turbine per year. Bat mortality at wind farms appears to be higher than bird mortality and in the eastern U.S. averaged 21-48 fatalities per turbine per year. Any individual site could differ substantially from these numbers.
- Various governmental organizations recommend wildlife evaluations that include pre-development use and habitat surveys, post-construction monitoring, and mitigation measures as needed. The U.S. Fish and Wildlife Service recommends avoiding placement of turbines or turbine arrays in known areas of high bird or bat concentrations. Turbine design and operation recommendations include discouraging roosting or nesting, adjusting FAA warning lights, and collecting ~3 years of monitoring data.

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The Health and Safety Subcommittee of the Committee for Renewable Energy for Barrington (CREB) was formed on July 7, 2008 with the task of providing a report on health and safety issues by August 15, 2008. Following concerns of town residents, a charge was established to advise the public and CREB on facts regarding health and safety issues of wind turbines. The Health and Safety Subcommittee worked with the purposes of:

1. collecting available information through searches by its own members and through those of concerned community members who sent references to CREB;
2. assessing the usefulness and credibility of currently available information;
3. summarizing the most useful, credible, and relevant information.

This report is not intended to be a comprehensive analysis of the proposed siting of a wind turbine in Barrington, nor is it a thorough review of all available information. Rather, it reflects the efforts of this group to develop an informational document on health and safety in a relatively short time frame for the benefit of the entire community.

This report focuses on health and safety concerns of wind turbines rather than positive impacts of renewable energy and the motivating effect that development of wind energy in Barrington might have on surrounding communities. Nevertheless, these positive factors should be kept in mind when reading this report. Levy et al. (2000) estimated that sulfur dioxide and other emissions from the coal-fired Brayton Point Power Plant in Somerset, MA are responsible for 106 premature deaths per year, 1,140 emergency room visits per year, 28,900 asthma attacks per year, and 199,000 daily incidents of upper respiratory symptoms. Per-capita health risks are greatest near the plant, but more than 90% of affected individuals live 30 miles or more from the plant. These estimates do not take into account the health and safety impacts of mining the coal to fire the plant, nor do they consider the impact on wildlife of coal mining and production of gases that contribute to climate change and habitat degradation. A single wind turbine producing 1.5 million kWh/year such as that at Barrington would displace only a tiny fraction of the 8.9 billion kWh/year generated at Brayton Point, but the turbine would reduce emissions by approximately 6,900 tons of carbon dioxide per year and 24 tons of sulfur dioxide per year, based on the Rhode Island Disclosure Label for the standard mix of electricity sources (http://www.newenglandgreen.org/downloads/RI_NEGS_DL.pdf).

The five major areas of health and safety covered in this report are:

1. Structural failure
2. Noise
3. Icing
4. Shadow flicker
5. Wildlife impacts

As the subcommittee reviewed available information, we attempted critically to apply several criteria regarding the usefulness and credibility of sources of information:

1. The recency of the information, due to the fact that wind turbine technology has progressed rapidly in recent years;
2. The use of evidence in the form of quantitative or qualitative data or calculations;
3. Indication of peer review;
4. Relevance to the Barrington situation, e.g. size and number of turbines in operation, turbine setting (urban, suburban, rural);
5. The apparent neutrality of the source, such as whether the source has no evident financial interest in the wind industry, is an academic source, avoids unqualified statements or statements unsubstantiated by actual studies, and does not contain blatant errors;
6. Public availability of the information, so that any person can obtain and review the source on their own.

Sources that did not meet these criteria were not rejected out of hand but were given a lesser weight. All of the information was checked against other sources to the greatest extent possible.

One of the sources, the Renewable Energy Research Laboratory at the University of Massachusetts at Amherst, which produced the white paper "Wind Turbine Acoustic Noise," was contacted directly, and one of the staff members, Senior Research Associate Bill Stein, provided guidance on use of the data and equations in the white paper.

The information that follows is related as closely as possible to the turbine under study in Barrington: a 600 kilowatt (kW) single turbine producing 1.5 million kWh per year, with tower height of 75 meters (m) (246 ft), rotor diameter of 50 m (164 ft), and total height of 100 m (328 ft). Two sites are under consideration in Barrington: the primary site at Legion Way (http://www.barringtonenergy.com/barrington_wind_turbine_site), which is just over 1,000 ft from the closest dwelling; and a secondary site at Barrington High School which is 190 ft from the school and about 500 ft from the nearest dwelling.

Reference

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STRUCTURAL FAILURE

Introduction

Currently, there are approximately 75,000 wind turbines operating worldwide, both singly and in wind farms, with a total rated capacity of 93,900 megawatt (MW)[1] (Global Wind Energy Council, 2008). Total wind turbine capacity grew by 27% during 2007, and continued increases are expected in the future due to rising energy prices and other factors. In light of the worldwide proliferation of wind turbines and their proximity to people, the need to guard against turbine structural failure is of increasing importance. Siting requirements to offset any potential failure during construction or operation are under review in some locales.

Wind Turbine Construction

The primary structural components of a wind turbine are the foundation, the tower, the nacelle (which supports the turbine axis and houses the generator), and the rotor. The foundation is composed of concrete set deep into the ground. Modern towers consist of a tapered, hollow tube of metal. The rotor is normally constructed of a glass fiber-reinforced polymer composite that provides a high strength-to-weight ratio. Rotor designs are a compromise between aerodynamic characteristics and structural strength (Sohn et al., 2006). The structure must support its own weight, the forces generated from rotation, and the additional weight and momentum of any snow or ice that temporarily accumulates on the structure.

According to the Danish Wind Industry Association (2008), wind turbines must be designed to withstand two kinds of loads: high loads that result from extreme winds, and smaller oscillatory loads that occur during normal operation. Not only must the structure be able to sustain maximum loads but also withstand the fatigue resulting from small, normal loads that can accumulate incrementally during millions of cycles. The California Energy Commission (2006) has documented significant numbers of failures involving blades and blade fragments being thrown up to 900 ft from large turbines. Many of the failures were of blades manufactured in the 1980s. Lightning strikes and storms are the most common causes of structural failures.

Manufacturing quality is a major factor in the integrity of any structure. Flawed material mixes can weaken the structure so that it cannot sustain even normal operating loads for short times. Recently, the India-based firm Suzlon Energy Ltd. had to reinforce all 1,200 blades sold in the U.S. because 65 of its giant blades had cracked under high wind conditions (Wall Street Journal, 2008). Edison Mission Energy, a large U.S. customer, cancelled orders for 150 turbines because Suzlon had been unable to determine the cause of the blade cracking.

Both General Electric and Vestas, two reputable wind turbine firms, have long back orders. G.E.'s back order now runs into 2010. Shorter turnaround times, with possible structural failure risks, may be associated with less experienced manufacturers.

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[1] A megawatt (MW) is equal to one million watts or 1,000 kilowatts (kW) (1000 kW = 1 MW).

Health and Safety Track Record

Caithness Windfarm Information Forum is an advocacy group in Scotland that opposes wind farm development in its area. This group provides the best available data on injury statistics related to wind power systems from press reports or official information releases from all over the world dating from 1975 through June 30, 2008 (Caithness, 2008). During this time, there were 49 deaths reported, none caused by structural failure. Deaths resulted mainly from accidents during transport, falling by maintenance workers, or distraction of drivers going by the turbine. The vast majority of victims were wind power industry workers. There were 14 public deaths, related primarily to transport accidents and aircraft incidents, but none of these was related to structural/blade failure.

Five non-lethal injuries to the public have been reported since 1975, of which one case involved structural/blade failure: spinal injury from a falling turbine part (Incident 130 in the detailed accident report). That accident occurred when "the turbine was being dismantled for inspection after the blades had stopped turning," i.e. outside of normal operating conditions.

Caithness (2008) posits that their database is incomplete and that accidents before 1999/2000 are under-reported. Data on failure rates in Rademakers and Braam (2005) agree with the data in Caithness (2008). Caithness (2008) also points out that the number of failures has increased along with the number of turbines put into production.

In summary, *although structural failures have occurred, to date all but one of the documented injuries from wind turbines have been associated with accidents involving wind industry workers and not structural failure. Incidence of accidents is rising as the number of turbines in service increases. Attention to safety in transport, installation, and maintenance is essential in reducing the risk of injury.*

Types of Failures Associated with Wind Turbines

According to Caithness (2008), rotor failure represented the largest number of incidents worldwide (16 in 2007), followed by fire (11) and structural failure of major components such as towers (11). The types of rotor failures that are possible range from full blade failure to partial damage due to lightning strikes (California Energy Commission, 2006).

For a risk analysis, Rademakers and Braam (2005) developed five categories of failure, cited verbatim below:

1. Whole turbine blades or very large blade pieces breaking off and being thrown.
2. Brake tips [plates activated to slow down the rotor] and other blade pieces such as blade surface panels, composite material, bolts, etc. being thrown from the turbine.
3. Tower collapsing.
4. Large parts, such as the nacelle, the whole rotor, or other main components falling down.
5. Small parts, such as the anemometer (wind speed meter) or bolts, falling down from the nacelle or the hub.

Failure Probabilities

As for any human-made structure, the fact that failure *can* occur must be considered in light of the *likelihood* that a failure occurs. This likelihood is expressed in terms of the probability of failure per turbine per year. Such probabilities are arrived at by counting the incidence of failures worldwide over the number of operating turbines over a number of years. Thus, the total count includes turbines that have been in service for a long time. The probability of failure of a new turbine should be lower than that for the entire fleet of turbines in service because of constant improvements in design and materials. Additionally, the probability of failure of a turbine purchased now can be influenced by factors that are under the control of the purchaser, e.g.:

- Dealing with reputable manufacturers that have a good, well-documented safety record.
- Careful installation by a reputable contractor.
- Attentive maintenance and routine inspection of the turbine.

Rademakers and Braam (2005) conducted a literature survey of reported turbine failures in any of the five categories listed above in California and from Danish, German, and Dutch reports. From this, the probabilities of failure were estimated to be:

Failure at nominal operating speed	420×10^{-6} per turbine year [2]
Failure at 1.25 times nominal operating speed	420×10^{-6} per turbine year
Failure at 2 times nominal operating speed	5×10^{-6} per turbine year

The failure probabilities of individual parts of the turbine were estimated by Rademakers and Braam (2005) as follows:

Turbine Part	Totals from German and Danish Databases		Probability of Failure	
	Number of Incidents	Turbine-Years	Mean Estimate	95% Upper Limit Estimate
Blades	27	42,889	630×10^{-6}	840×10^{-6}
Tips	3	24,006	120×10^{-6}	260×10^{-6}
Nacelle	8.5	42,889	200×10^{-6}	320×10^{-6}
Tower	2.5	42,889	58×10^{-6}	130×10^{-6}
Small Parts	21	17,452	$1,200 \times 10^{-6}$	$1,700 \times 10^{-6}$

In summary, *the worldwide incidence of structural failures is on the order of 420 per million turbine years. This means that each turbine has a risk of blade or other failure of about 1 in 2400 in a given year. The probability of failure of a new turbine can be lowered by dealing with reliable manufacturers and contractors and following good maintenance and operational practices.*

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[2] 420×10^{-6} per turbine year means a probability of 420 failures per million turbine years.

Probability of Injury

That failure occurs does not necessarily mean that injury to a person results. For injury to occur, the turbine must undergo failure in a hazardous way, and a person must be within harm's way at the time of failure. This line of inquiry leads to throw analysis of turbine debris under failure, combined with the probability that a piece of debris will fall in a certain area, combined with the probability that a person is in that area.

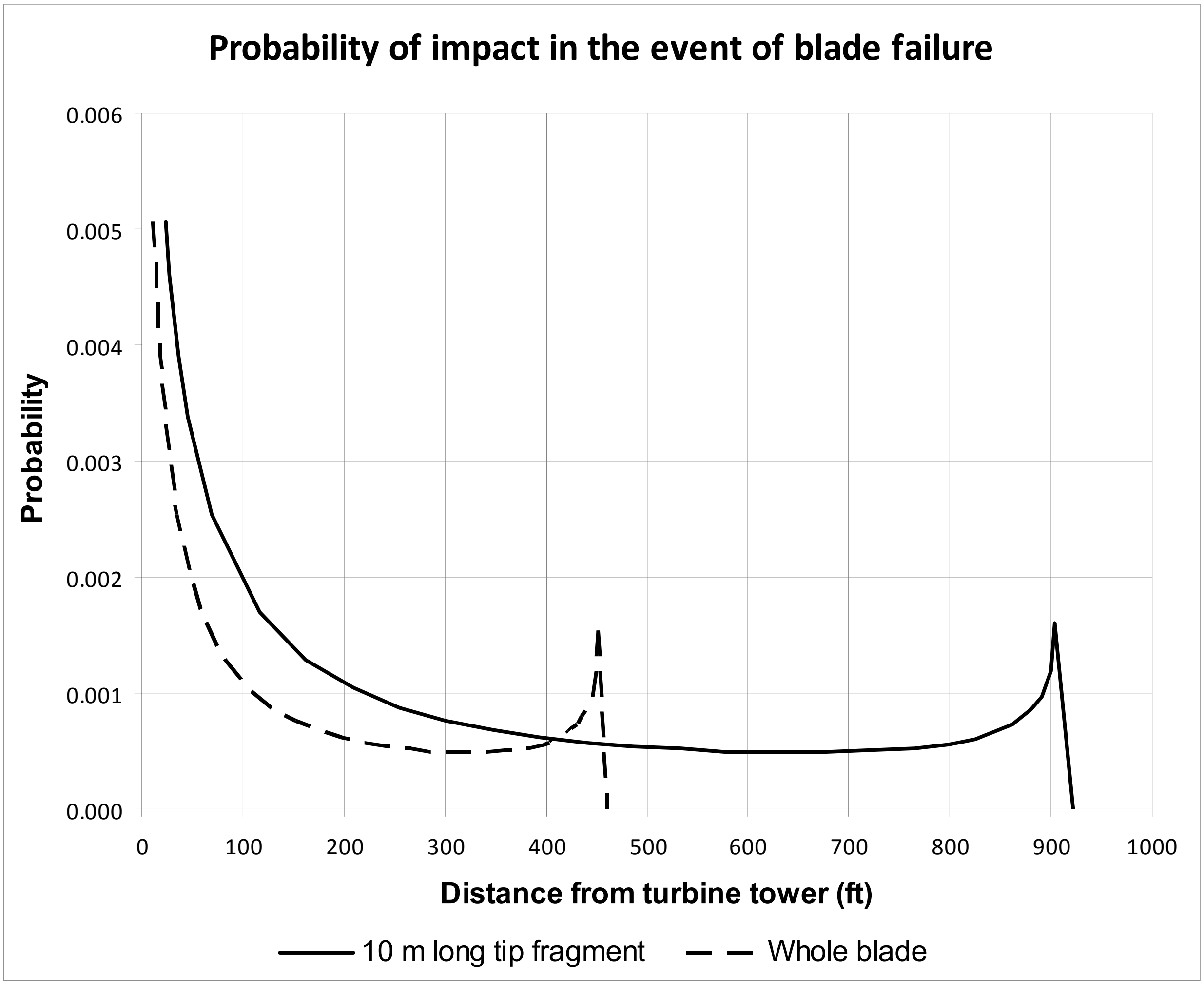
For the probability that a person is in the area, we assume a probability of 1, the idea being that people may be on a property almost continuously. In other words, we will show probabilities of a person being injured if there are people at a location year-round that is within the zone that debris can reach.

The calculations that follow were performed by David Hawla of the Health and Safety Subcommittee following the recommendations of the California Energy Commission (2006). The calculations were carried out roughly as follows:

- Verified the calculations in California Energy Commission (2006).
- Computed the maximum throw distance for two cases: (1) a large, 10 m long fragment from the blade tip, and (2) a whole blade.
- Used the maximum blade throw distances to convert the verified calculations from non-dimensional distance to distances in feet for a turbine with the dimensions of the proposed Barrington turbine operating at a rotational speed of 22 rpm.
- Then computed an approximate probability of injury to someone who remains in this area at the maximum throw distance.

The calculations of blade throw distance neglect wind resistance. In reality, the blades are often thrown during storms. However, the simplifying assumption of no wind resistance is based on the fact that much more sophisticated calculations referred to in California Energy Commission (2006) suggest that aerodynamic effects for large debris do not change the distances thrown significantly. If the blade or fragment were launched while no wind was blowing, aerodynamic drag would shorten the distance; during a storm, the wind would blow the blade downwind, most likely perpendicular to the direction of launch. In the calculations, the direction of throw was assumed to be random, and the angle of launch was also assumed to be random. Tip fragments smaller than 10 m would leave with a higher speed at their center of gravity but would be more subject to wind resistance and therefore not be thrown as far.

Calculations for the fragment and whole blade are depicted in the following chart.



The above graph shows that, in the event of blade failure, the probability of being hit is highest within the first hundred feet, flattens out, then rises to another peak of 0.0016 near the maximum throw distance of 450 ft for a whole blade and 900 ft for a tip fragment.

The probability of injury is the probability of being hit by a blade or fragment near the maximum throw, 0.0016, multiplied by the 95% upper limit probability for blade and fragment failure per the recommendation of Rademakers and Braam (2005) in the table given earlier. This gives:

- Probability of injury near the whole-blade-throw maximum distance of 450 ft $= 0.0016 \times 840 \times 10^{-6} = \mathbf{1.3 \times 10^{-6}}$ per person per year (i.e. a risk of 1.3 in one million per person per year).
- Probability of injury near the 10 m-tip-fragment-throw maximum distance of 900 ft $= 0.0016 \times 260 \times 10^{-6} = \mathbf{0.4 \times 10^{-6}}$ per person per year (i.e. a risk of 4 in ten million per person per year).

The probabilities are lower than these at distances between 150 ft and the maximum throw distance.

For comparison, the following table shows probabilities for other kinds of risks as given by Ropeik and Gray (2002).

Cause of death or harm (in the U.S.)	**Probability of death or injury per person per year**
Death in motor vehicle	149×10^{-6}
Struck by falling object	3×10^{-6}
Hit by lightning	0.3×10^{-6}
Death by homicide	56×10^{-6}
Death by gun	36×10^{-6}
Death on the job	21×10^{-6}
Death from electrocution	3×10^{-6}

The above charts and table indicate that:

- A person who remains all year long at a distance of just under 900 ft from the turbine has a probability of about 0.4×10^{-6} per year of being hit by a blade tip fragment. This is about the same probability of being hit by lightning in a year.
- A person who remains all year long at a distance of just under 450 ft from the turbine has a probability of about 1.3×10^{-6} per year of being hit by a whole blade. This is about half the probability of dying from electrocution in a year.

For the Barrington High School location, at any given time of the day, many people would be within the maximum throw distances of 450 or 900 ft, because students would be in their classrooms, students may be on the playing fields, and sections of two busy roads, Federal Road and County Road, lie within this distance. A 900 ft setback, such as that associated with Legion Way, would essentially eliminate the chance of injury due to structural failure.

In summary, *a person who remains all year long at a distance of just under 900 ft from the turbine has a probability of being hit by a blade tip fragment about the same as being hit by lightning. A person who remains all year long at a distance of just under 450 ft has a probability of being hit by a whole blade about half the chance of being electrocuted in a year. A 900 ft or greater setback such as that at Legion Way essentially eliminates the chance of injury due to structural failure.*

Permitting Setbacks

A simpler approach to dealing with failure risks is to assure setbacks that obviate the need for calculating the probability of injury. The purpose of the California Energy Commission (2006) study was to review the setbacks associated with turbine structural safety, excluding noise considerations or icing.

In California, setbacks are prescribed as a multiple of turbine height or a fixed distance, whichever is greater. Below are the setbacks from turbines to dwellings, which are more stringent (larger) than those to property lines or roads.

Municipality	Basis of Setback (whichever is greater)		Municipality Setback Applied to Proposed Turbine with a Height of 328 feet
	Number of turbine heights	Fixed distance, ft	
Alameda County	3	500	984
Contra Costa County	--	1,000	1,000
Kern County	4	1,000	1,312
Riverside County	3	500	984
Solano County	3	1,000	1,000

Given that accidents can occur while turbines are undergoing maintenance or repair (Caithness, 2008), a temporary exclusion zone is probably the norm during such periods.

In summary, *setbacks for structural safety are typically in the range of 1,000 ft from the nearest dwelling, comparable to the distance to dwellings at the Barrington Legion Way site but larger than the 190 ft at the high school site.*

Structural Failure References

Caithness. 2008. Summary of wind turbine accident data to June 30, 2008. Caithness Windfarm Information Forum. http://www.caithnesswindfarms.co.uk/.

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NOISE

Characterizing Sound

Sound consists of fluctuations in air pressure that are transmitted as waves and are detected by the human ear. Sound is a mixture of frequencies and varying degrees of strength at each frequency.

Frequency of sound is the number of pressure waves transmitted per unit time, typically expressed as cycles per second, or Hertz (Hz). The frequencies that humans can normally detect range from 20 Hz to 20,000 Hz, with greatest sensitivity in the range of 1,000 to 4,000 Hz. Humans perceive the frequency of sound as *pitch*, with higher-frequency sounds associated with higher pitches. All sounds except those considered "pure tones" contain a spectrum of frequencies, and it is this spectrum that gives any particular sound its recognizable quality. Notes, hums, and whines tend to be concentrated at particular frequencies, while atonal sounds are spread over a broad band of frequencies.

The strength of sound – the amplitude of the sound waves – is perceived by humans as *volume*. Because humans are capable of detecting sound waves over an enormous range of loudness, a logarithmic scale is used to express sound volume. Sound pressure level is expressed in terms of the decibel (dB), which equals 20 times the log base 10 of the ratio of the sound pressure to a standard pressure of 20 microPascals (a unit of pressure), the lower limit of human hearing. Because the sensitivity of the human ear varies with pitch, the A rating scale was designed to average the sound volume over all frequencies, giving more weight in the range of pitch in which the human ear is most sensitive. The C rating puts greater emphasis on low frequencies.

Because the dB scale is logarithmic, each increment in dB level represents a multiplication of sound volume. For example, every 6 dB increase in sound pressure level represents a doubling of sound volume. Thus, 52 dB is twice as loud as 46 dB, which is twice as loud as 40 dB. Increasing the dB level by 10 multiplies the sound pressure level by 20 (not 10, as stated by Pierpont, 2006).

Sound pressure level decreases with distance from the source. There are three reasons for this: absorption and scattering by the surface over which the sound is traveling, dissipation of the sound energy due to friction of the air molecules with each other, and the spreading of sound energy over an ever-increasing area (the last one being the greatest effect). Because sound pressure waves spread out spherically through the air, the area over which the sound energy is distributed grows with distance from the source, and the energy per unit area becomes less. For example, doubling the distance from the source causes the sound pressure level to decrease by 6 dB. Building materials also dampen sound transmission through walls and windows. Typical sound level reductions inside buildings in our region are 17 dB with windows open and 27 dB with windows closed (Noise Pollution Clearinghouse).

According to EPA data cited in a Toronto Staff Report (1999), ambient background sound pressure levels are 45-52 dB in quiet suburban settings, 53-57 dB in normal suburban settings, 58-62 dB in urban settings, 63-67 dB in noisy urban settings, and 68-72 dB in very noisy urban settings. A sound pressure level of 60 dB is that of ordinary conversation in an otherwise quiet living room, 40 dB a soft whisper 6 ft away in a library, and 20 dB that inside an unoccupied soundproof studio. These values are approximate.

Noise Issues Associated with Wind Turbines

Noise is any unwanted sound. When noise is of a sufficient volume and duration, it can cause annoyance, interference with sleep or learning, or hearing damage at high levels. In determining the problem that a noise may represent, it is important to consider the characteristics of the noise as well as those of the receiver (Rogers et al., 2006).

Whether noise from wind turbines is of concern depends on a number of factors:

1. *The sound volume and frequency spectrum of the noise.* Tonal sounds like a hum or a whine can emanate from the gearbox of the turbine, although this sound is reduced in newer turbines; broadband (atonal) sound emanates from the turbine blades moving through air; and low-frequency sound is emitted primarily from the turbine moving past the tower (less important in modern turbines, where the blades rotate upwind of the tower).
2. *Wind speed.* Noise from wind turbines increases with wind speed (Rogers et al., 2006). At most, noise increases about 3.3 dB for each 1 m/s (2¼ mph) rise in wind speed (specifically, at the top of the tower, the noisiest wind turbine reported by this source produced 90 dB at 6 m/s and 110 dB at 12 m/s).
3. *Patterns of noise emission.* Even when the overall dB level is acceptable, rhythmic variations or other patterns can be an annoyance.
4. *Background sound levels.* Background sound can mask noise or contribute to it. Background noise also increases with wind speed, rising about 3.3 dB for every 1 m/s (2¼ mph) increase in wind speed (Rogers et al., 2006).
5. *Landscape*. The terrain between the emitter and receiver affects the transmission of sound. Ground cover and walls can reflect back (amplify) or scatter (disperse) sound as it propagates.
6. *Personal response.* The person's sensitivity to sound, their activity at the time, or their personal reaction to the qualities of the sound affect response. Reactions to sound are subjective and vary from person to person.

Sound levels increase with rotor speed and turbine blade diameter, which is related to the rated power output of the turbine. Thus, one must be careful in making comparisons of noise from wind turbines that are significantly larger or smaller than the proposed Barrington wind turbine or are part of a wind farm of multiple turbines. For example, Frey and Hadden (2006) provide an assessment of the impact of industrial-scale, 740-2,000 kW turbines in wind farms. Harry (2007) surveyed people in Britain living 300 m to 2 km (980 to 6,560 ft) from wind farms rather than single turbines. The Macalester College turbine, which sits on an urban campus in Minneapolis with no reported adverse effects (http://www.macalester.edu/maccares/turbine.htm), is rated at only 10 kW.

Barrington resident Tony Caner spoke to residents who live close to the Hull1 and Hull2 turbines in Hull, MA and the Portsmouth Abbey turbine in Portsmouth, RI. His statement is presented below:

> I drove to the turbine sites, listened to the noise myself, took some pictures and some video to document my visit, went and talked with any abutters or residents living nearby that were home, and made mental notes. When talking to abutters, I told them that I was from Barrington, RI, that we were investigating putting a turbine up in our town, and wanted to get input from folks who were living near turbines as to what they thought about them and what, if any, were the benefits and problems. I did not take names and addresses (although I can identify where the residents lived) nor color my discussion with my own opinions, but I did ask about whether or not they noticed noise and/or flicker.
>
> Hull:
> I spoke with four residents close to Hull2 Turbine (the same size as the one proposed in Barrington, but a larger generating capacity)
>
> 1. Lives 350 feet from the Hull2 turbine. Noise and flicker, which he acknowledged, don't bother him.
> 2. Lives 500 feet from Hull2. Noise is bothersome.
> 3. Lives 650 feet from Hull2. Noise is "soothing" but flicker bothers them, makes wife nauseous.
> 4. Lives 700 feet from Hull2. Loves the turbine!
>
> I spoke with two residents close to Hull1Turbine (225 feet from High School)
>
> 1. Lives 750 feet from the Hull1 turbine. Doesn't hear any noise and doesn't see any flicker. Thinks it's great!
> 2. Lives 730 feet from Hull1 turbine. Doesn't hear any noise and doesn't see any flicker. Thinks it's great!
>
> The residents near Hull1 are sheltered from the turbine by the high school buildings, so they don't have direct exposure to the flicker and noise.
>
> Portsmouth:
> I spoke with four residents close to Portsmouth Abbey Turbine (smaller in height the one proposed in Barrington, but similar generating capacity)
>
> 1. Lives 550 feet from the Abbey turbine. Noise bothers them so much they had to move their bedroom from the turbine side of the house to the opposite side (back to front).
> 2. Lives 640 feet from Abbey turbine. Noise is bothersome.
> 3. Lives 730 feet from Abbey turbine. Noise is bothersome, don't like sitting in backyard in the evening because of the noise.
> 4. Absentee landlord property 660 feet from Abbey turbine. Tenants haven't complained.

In summary, *noise issues can be of serious concern for some people who live near turbines. The significance of problems varies with size and number of turbines, distance from the turbine, and the terrain between turbine and receiver. Noise disturbance is subjective, and sources differ on the severity of the problem.*

Interaction with Ambient Noise

Ambient, or background, noise levels are a factor in assessing wind turbine noise. Because of the logarithmic nature of the dB scale, the combination of wind-turbine and background sounds does not result in the simple addition of their dB level. Rather, one sound, if substantially louder than another, will effectively mask the other. For example, if a 50 and 56 dB sound are combined, the total dB will be 57 dB. If two 50-dB sources are combined, the total level will be 53 dB.

For this reason, noise produced in quiet settings has a greater effect than in noisy settings. Turbine noise at night will be more audible, because ambient noise is lower at night. And noise whose frequencies are markedly different from ambient sound can stand out even when the noise has a lower dB level than the ambient.

van den Berg (2006) found that turbine noise on clear, calm nights is more intrusive than would be expected from ground-level wind speeds. Wind increases both turbine noise and ambient noise at ground level, and therefore turbine noise may be masked by background noise in windy conditions. However, at night, wind speeds at turbine height may be substantial even when ground conditions are still. Thus, nighttime conditions that are windless on the ground, when ambient noise is low, can still be associated with wind at turbine height, resulting in a greater perception of turbine noise at night. van den Berg recommends a “penalty” of 5 dB for turbine noise levels on clear, calm nights, which effectively means that turbine noise is considered effectively to be 5 dB greater than actually measured.

In summary, *turbine noise is more audible at night than in daytime, especially on calm, clear nights when wind at ground level is insignificant but the wind at turbine height can still drive the turbine.*

Low Frequency Noise and Loudness Fluctuations

Low frequency noise is unwanted sound at very low pitches, typically below 100 Hz. Infrasound is sound at pitches below the range of human hearing, 20 Hz. Sufficiently strong, low-frequency sounds can have the same effects as loud sounds in the audible range – annoyance, interference, or damage. However, dB levels at which these effects accrue are higher than those in the audible range (Rogers, 2006). Typically, 90 dB is considered the threshold of perception at low frequencies (Rogers, 2006). Stewart (2006) shows data indicating that minimum detectable level is 30 dB at 100 Hz and rises to 100 dB as frequency decreases to 10 Hz.

Turbine blades produce low-frequency sounds. According to sound studies cited by Rogers (2006), maximum sound pressure levels at low frequencies for turbines of 450-2,000 kW are below the human sensation threshold of 90 dB, and there is no evidence of adverse effects from low-frequency sound below 90 dB. Low-frequency noise levels from a Vestas V-52 850 kW wind turbine were 70 dB or less at a 10 m/s (22 mph) wind speed at a distance of 80 m (260 ft) from the turbine (Rogers, 2006).

An aspect of noise emitted by wind turbines is a "swish-swish" sound associated with changes in the relative distances between the three turbine blades and a receiver. This characteristic is referred to as low-frequency amplitude modulation, which means that the loudness of the sound fluctuates at a rate associated with the speed of the rotor. Overall sound pressure levels are averages that do not reflect these fluctuations, but these fluctuations can increase annoyance. Pedersen and Persson Waye (2007) found that 51% of people were annoyed by low frequency amplitude modulation at wind farms at a sound level of 37.5-40 dB, and 56% were annoyed above 40 dB, greater than industrial noise at the same dB level. Two or more turbines can contribute to this effect, because modulations that drift in and out of sync between turbines are more noticeable. Stewart (2006) provides a broad summary of wind farm noise that describes this and other effects.

In summary, *low-frequency loudness variations, a "swish-swish" sound, increase the annoyance of turbine noise, an effect not taken into account by overall average dB levels. Wind turbines produce infrasound but do so at levels below 90 dB, the detectable level below which there is no evidence of adverse effects.*

Noise Regulations

Environmental noise policies exist at the federal, state, and local levels. Rhode Island has no noise exposure criteria.

At the federal level, environmental noise policies vary with agency (Bastasch, 2006). Bastasch lists regulations of 49 dB for the U.S. Environmental Protection Agency and the Federal Energy Regulatory Commission, 59 dB for the FAA and U.S. Housing and Urban Development, and 67 dB for the Federal Highway Administration.

State criteria regulate various aspects of noise, including its intermittence, beat frequency, and shrillness, among other characteristics (Bastasch, 2006). Some regulations impose a penalty of 5 dB if there is a defined tonal quality to the noise, which means that the measured sound level is treated as being 5 dB higher than measured. Oregon has a new wind turbine noise standard (Oregon WTN Standard) that restricts to 10 dB any increase in ambient noise levels to a maximum of 50 dB; this restriction only applies when the combined sound is above 36 dB.

The Massachusetts Department of Environmental Protection (1990) limits new broadband (atonal) sound sources to raising sound level no more than 10 dB above ambient, where ambient is defined as L_{90}, the sound level exceeded 90% of the time. However, any particular tone may be no greater than 3 dB above the sound levels of tones close to the same pitch; this prevents a hum or a whine from standing out.

The International Finance Corporation (2007) specifies that noise from wind turbines should not increase background levels more than 3 dB at the nearest receptor location. This is the most restrictive guideline we have found.

The American National Standard Acoustical Performance Criteria for schools (ANSI, 2002) prescribes indoor background noise levels of less than 35 dB in smaller learning spaces (less than

20,000 cubic feet) and less than 40 dB in larger spaces. If the building structure itself reduces the outdoor noise level by 27 dB with windows closed (Noise Pollution Clearinghouse), then the outdoor noise level should be 62 dB or less near schools, approximately that for urban settings (Toronto Staff Report, 1999).

Noise standards in other countries were reviewed by Rogers et al. (2006). For residential areas, the limits are 40 dB in Denmark, 55 (day) and 40 (night) in Germany, and 45 (day) and 35 (night) in the Netherlands. The International Finance Corporation (2007) cites 1999 World Health Organization noise-level guidelines of 55 dB outside during the day (7 a.m. to 10 p.m.) and 45 dB outside at night (10 p.m. to 7 a.m.) for residential, institutional, and educational receptors, and 30 dB at night inside a building.

In summary, *noise restrictions are 49-67 dB for U.S. federal agencies, and 35-45 dB at night in Europe. Massachusetts and Oregon limit new broadband (atonal) sounds to 10 dB above ambient. The World Health Organization sets limits of 55 dB outside during the day, 45 dB outside at night, and 30 dB indoors at night for sleeping. The American National Standards Institute limits indoor background noises to 35 dB in classrooms.*

Overall Noise Emission by Wind Turbines

Rogers et al. (2006) provided data and descriptive equations with which to estimate the overall noise levels from individual wind turbines at various distances.

Rogers et al. (2006) give the sound pressure level in dB at rated rotor speed as a function of turbine diameter for wind turbines constructed in the 1980s and those constructed in the 1990s and 2000s. Sound pressure level increases with turbine diameter but is substantially lower in newer turbines, being about 9 dB lower at the hub with a 50 m diameter rotor. For the proposed Barrington turbine, the sound pressure level at the hub is calculated to be 101 dB[3] (Fuhrlander specifies 98 dB for their 600 kW turbine). The decrease in sound pressure level with distance from the turbine was then calculated for the proposed Barrington turbine using the approach given by Rogers et al. (2006).[4] Their equation assumes a spreading of sound energy in a hemispherical shape that neglects absorption; this projects 3-dB higher sound pressure levels than a spherical shape (the Danish Wind Industry Association uses the less conservative, spherical assumption). The following figure shows the calculated sound pressure level in dB as a function of horizontal distance from the turbine, i.e. the setback.

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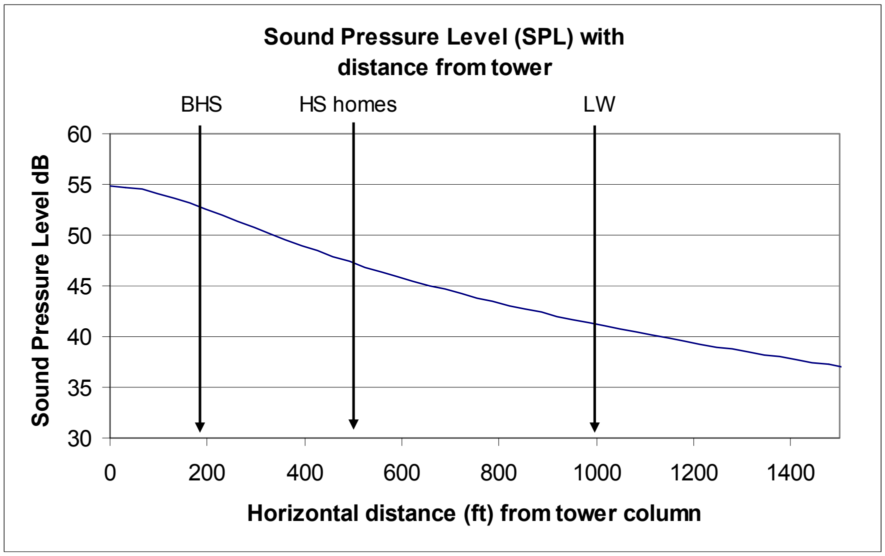
[3] The equation for newer turbines is $L_w = 11 \log_{10}(D) + 82$ where L_w = sound pressure level in dB at rated speed, D is the rotor diameter in meters.

[4] The decrease in sound pressure level with distance from the turbine is calculated as $L_p = L_w - 10\log_{10}(2\pi R^2) - \alpha R$, where L_p is the sound pressure level at a distance R (in m) from the source, and α is the coefficient for sound absorption by the landscape, commonly taken as 0.005 (setting α to zero changes the results by only 2 dB at 1500 ft).



These estimates are consistent with those cited by other sources. The Ohio Department of Health (2008) reported that single turbines produce 50-60 dB at 120 ft and 35-45 dB at 900-1,000 ft. The Toronto Staff Report (1999) provides data from Vestas 660 kW and Tacke 600 kW turbines in the ranges of 50 dB at 330 ft, 44-46 dB at 660 ft, and 39-43 dB at 980 ft. All of these numbers are close to the graph shown above.

Noise Levels at the Barrington Sites

Three points of interest are the setbacks associated with the Barrington High School (**BHS**) site of 190 ft, the distance of 500 ft to the nearest dwelling at the high school site (**HS homes**), and the distance of 1,000 ft to the nearest homes at the Legion Way (**LW**) site. The above graph shows that sound pressure levels would be approximately 53 dB at the high school, 47 dB at the home nearest the high school, and 41 dB at Legion Way.

As noted earlier, noise at night is more critical. With interior noise at night limited to 30 dB for sleeping (World Health Organization, 1999), the external sound level should be limited to 47 dB with windows open and 57 dB with windows closed, using the Noise Pollution Clearinghouse estimates of 17 dB and 27 dB sound drops across insulated walls with open and closed windows, respectively. With a 5 dB penalty for low-frequency amplitude modulation, the noise limit would be 42 dB, which corresponds to a distance of about 900 ft as seen in the graph above.

The table below summarizes the estimated exterior and interior noise levels for the two Barrington sites, along with mid-range noise standards that fall between U.S. federal agencies (49-57 dB) and European night standards (35-45 dB). The high school site produces external noise below day-time standards at the high school itself but above night-time standards at the nearest dwelling. Interior noise at the high school site either in dwellings or in the high school itself is acceptable only with windows closed. At Legion Way, turbine sounds are within WHO limits both during the day and at night, outdoors and indoors, even with windows open.

	Outdoor			Indoor		
	Estimated outdoor sound produced by wind turbine	*Mid-range outdoor sound limit during day*	*Mid-range outdoor sound limit at night*	Estimated indoor sound of wind turbine with windows open	Estimated indoor sound of wind turbine with windows closed	*Mid-range indoor sound limit*
BHS (190 ft)	53 dB	*55 dB*	*45 dB*	36 dB	26 dB	*35 dB (classroom)*
Dwellings at high school site (500 ft)	47 dB	*55 dB*	*45 dB*	30 dB	20 dB	*30 dB (night)*
Legion Way (1,000 ft)	41 dB	*55 dB*	*45 dB*	24 dB	14 dB	*30 dB (night)*

Noise Setbacks

There is a great disparity of opinion on noise setbacks. Harrison (2008) cited noise-related studies such Frey and Hadden (2007), Harry (2007), and Stewart (2006) that call for noise setbacks from wind farms of 1 to 1.5 miles, far greater than the actual setbacks of most wind turbines.

On July 15, Barrington resident Ron Russo contacted the chief project engineer for the 600 kW Vestas wind turbine installed at Holy Name Senior High School in Worcester, MA. The engineer recommended a setback of 800 ft based primarily on noise and shadow flicker (see later section). The total height of this turbine is 74 m (242 ft) with a rotor diameter of 38 m (124 ft).

A 2007 siting study for offshore wind farms in Rhode Island conducted for the State of Rhode Island Economic Development Corporation cited a noise setback of 3 times the tower height to be "generally considered an appropriate distance to mitigate noise concerns" for single turbines (RIWINDS, 2007). For the proposed Barrington turbine, this would mean a setback of 222 m, or 728 ft – greater than that at the high school but within the setback at Legion Way.

In summary, *a wind turbine at Barrington High School is estimated to produce outdoor noise of 53 dB at the high school itself and 47 dB at the nearest dwelling. These levels are below the WHO daytime standard at the high school but above the WHO nighttime standard at the nearest dwelling. Interior noise either inside dwellings or in the high school itself is estimated to be well below WHO and ANSI standards only with windows closed. At Legion Way, outdoor noise at the nearest home is estimated to be 41 dB, resulting in sound levels that are within WHO standards both during the day and at night, outdoors and indoors, even with windows open. A noise limit of 42 dB, which accounts for various conditions including low frequency "swishing" sounds, is satisfied at distances of about 900 ft or greater from the proposed Barrington turbine.*

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ICING

Introduction

Ice can accumulate on wind turbines under the same wintry conditions in which it accumulates on any stationary or moving object. Ice is formed when liquid water precipitates and strikes a sub-freezing structure. Icing occurs when the ambient temperature is at or near freezing and the conditions are such that precipitation is unfrozen but ground structures are at or below freezing.

Icing of wind turbines can be a hazard to nearby persons or structures if ice on the turbine falls off or is thrown during rotation while still in solid form. This can happen when the temperature rises above freezing and the ice detaches from the structure. However, ice falling from a turbine at standstill still represents a risk, and ice that falls from the top of a turbine in windy conditions can be blown outside of the footprint of the turbine. Even before the advent of sophisticated sensors and controls, anecdotal evidence suggested that the tendency was for ice fragments to be dropped off rather than thrown (Morgan et al., 1998).

Current safety controls are designed to shut down the turbine when a predetermined amount of ice is formed. Icing can be indicated by detection of a difference in measured wind speed between a heated and unheated anemometer, or a fall in turbine output at a given wind speed.

According to Seifert et al. (2003), ice fragments thrown from rotors were primarily in the range of 0.1 to 1.0 kg (3 oz to 2.2 lbs) and landed mostly within 15 to 100 m (50 to 330 ft) of the turbine. An 0.1 kg ice fragment, if spherical, would have a diameter of 2.2 inches; a 2 lb ice fragment, if spherical, would have a diameter of almost 5 inches. Smaller ice fragments are affected more by the wind than larger fragments. Thus, in a strong wind, smaller fragments will be blown downwind further than larger fragments.

In summary, *icing on wind turbines occurs under the same wintry conditions as icing on other structures or plants. Ice fragments thrown from wind turbines have been reported as being typically up to 2 lbs and generally landing within 330 ft of wind turbines.*

Safety Incidents from Icing

In 1998, Morgan et al. reported that "there has been no reported injury from ice thrown from wind turbines." However, the recent compilation by Caithness (2008) of accidents from around the world found 23 incidents of ice fall or ice throw since 1975. Only one case resulted in human injury. However, safety concerns were raised in many of the incidents as evidenced by road closings or damaged cars.

Mitigation Strategies

Mitigation strategies for eliminating health and safety risks due to icing include (Morgan et al., 1998):

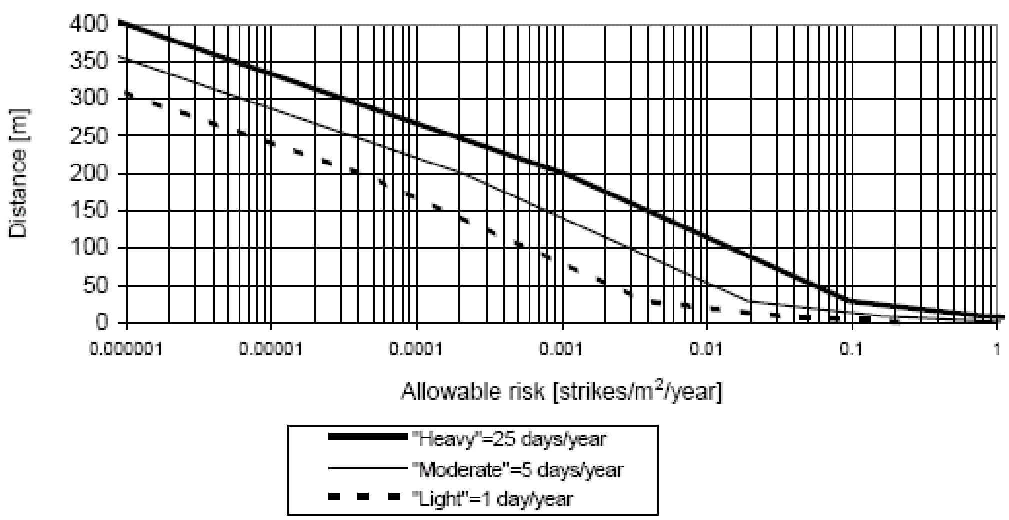
- Curtailing turbine operations during icing conditions, either automatically or with manual shutdown
- Using turbine features which reduce ice accretion such as black-colored fluoroethane-coated blades, which are reportedly more effective in light icing climates
- Siting of turbines away from areas of risk
- Warning people away from areas of risk
- Training operational staff to be aware of icing conditions

Heating of turbine blades or other forms of de-icing, like that used in the airline industry, is expensive, not overly effective, and not necessary, given other strategies like setbacks and automatic and manual shutdown (Baring-Gould, 2006).

Setbacks for Icing

One question about icing is how far ice would be thrown from a moving turbine, given turbine speed, angle of departure, and wind speed (Seifert et al., 2003). Such detailed analyses result in graphs such as Figures 3 and 4 in Seifert et al. (2003), which depict the potential zone of ice landing downwind from a rotor at various wind speeds.

Morgan et al. (1998) estimated ice fall probabilities on the basis of trajectory calculations and the area over which ice is spread. Their Figure 3, reproduced below, provides safe distances for a 50 m diameter rotor (comparable to the proposed Barrington turbine) with three levels of climatic incidence of icing (1, 5, and 25 days/year). Under the lowest probability shown, 10^{-6} strikes/m^2/year, the allowable setback is 300 m (984 ft) for icing conditions of 1 day/year.



Such detailed analyses have given way to simpler standards regarding setbacks. For ice *throw*, the most commonly cited setback is based on a maximum throw distance calculated from rotor diameter and hub height.[5] For the proposed Barrington turbine, this would result in a setback of 620 ft. For ice *falls* from a non-rotating turbine, for which distances are also dependent on wind

[5] d = 1.5 (D + H), where d = setback (m or ft), D = rotor diameter (m or ft), and H = hub height (m or ft) (Seifert et al., 2003; General Electric, 2006; Baring-Gould, 2006).

speed, the setback for the proposed Barrington turbine would be 365-730 ft at wind speeds of 20-40 mph, respectively.[6]

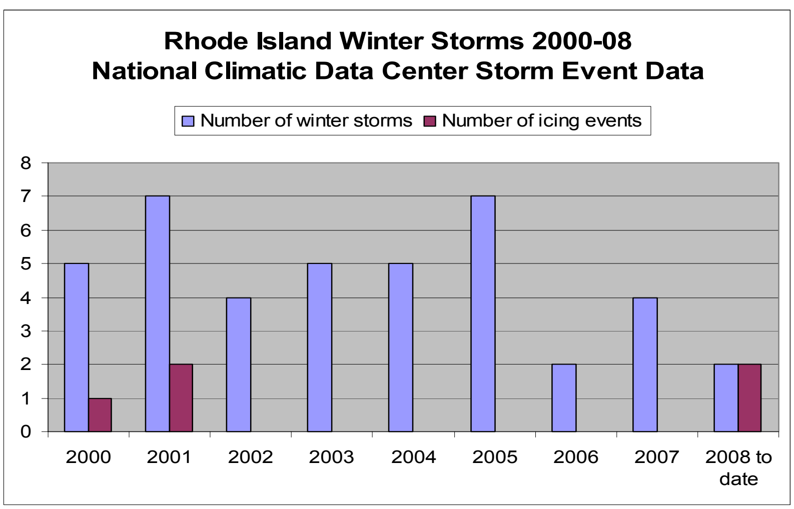
These values appear to be conservative. Data for ice throws in Seifert et al. (2003) show distances no greater than 125 m (410 ft). The compilation from Caithness (2008) reports ice at distances of 50, 70-80, 80, 85, 100, and 130 m (426 ft) from the turbine, although one report claims ice at 400 m (about 1,300 ft) from the turbine.

In summary, *industry rules-of-thumb for icing are based on tower height and turbine diameter and range between 620 and 730 feet for the proposed Barrington turbine. These setbacks are greater than virtually all reports of distances of ice fragments thrown or falling from turbines.*

Incidence of Icing in Barrington

Local icing conditions vary substantially and over short distances. Although it is recommended that data at a specific location be used to determine incidences of icing (Baring-Gould, 2006), a more conservative approach is to compile the incidences of icing statewide. Statewide data are available from the National Climatic Data Center (NCDC, 2008). The reports since the 1990s have more detailed descriptions than earlier reports, so we limit the results to 2000 and later.

The graph below depicts the total number of all "winter storms" (NCDC definition) in Rhode Island reported by the NCDC each calendar year.



Also shown is the number of winter storms that resulted in icing: those classified by the NCDC either as ice storms, as storms containing freezing rain, or as winter weather that produced icy conditions. While the number of winter storms in Rhode Island ranged from 2 to 7 (average of 4.6 storms per calendar year), the number of icing events ranged from 0 to 2 (average of 0.6

[6] D = 1.5 ν (D + H)/15 where d = falling distance (m or ft), D = rotor diameter (m or ft), and H = hub height (m or ft) and ν is wind speed (m/s or ft/s) (Baring-Gould, 2006).

events per calendar year). Assuming these data are representative, this places Rhode Island in the lowest of the three categories of icing defined by Morgan et al. (1998).

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SHADOW FLICKER AND LIGHTING EFFECTS

Introduction

As wind turbine blades rotate, they can cast a moving shadow of the sun, causing a strobe-like effect called shadow flicker that can be an annoyance. FAA safety lights and reflections for the sun are other potential annoyances. The scope and effects of flicker should be considered in siting wind turbines (International Finance Corporation, 2007), and steps should be taken to reduce or eliminate lighting effects.

The existence and intensity of shadow flicker are affected by a number of factors (Voll, 2006 and many others):

- The strength of the sun as affected by cloud cover.
- The line of sight of the observer relative to the sun and the turbine. This is related to the sun's height in the sky, which varies with latitude and longitude, time of day, and time of year.
- The distance between the observer and the turbine, which affects the distinctness of the shadows.
- The presence of obstructions such as buildings or vegetation.
- The orientation of the turbine depending on wind conditions. When the turbine is facing the sun, shadow flicker is greater behind the turbine; when the turbine is rotating in line with the sun, there is much less flicker.

In addition to shadow flicker, glint from sunlight reflecting off the blades is a possible lighting effect. The International Finance Corporation (2007) states that this effect disappears after a few months as the blades lose their shine.

Another form of lighting effect can arise from FAA safety lights placed on the tower. Whether these lights blink or are constant, they can constitute a form of light pollution. However, very few references raise this as an issue. In a survey conducted near a 22-turbine wind farm in Wisconsin, Bittner-Mackin (2006) reported that 9% of people who live 800-1300 ft (1/6 to ¼-mile) from the turbines were annoyed by blinking lights atop the towers, and 15% of those living ¼- to ½-mile were annoyed (note, however, that these effects pertained to a large wind farm). Benas (2006) notes that FAA lighting requirements should be met so as to control effects at ground level.

Impact of Shadow Flicker on Humans

German standards indicate that the blade must obscure more than 20% of the sun's orb in the sky to produce noticeable flicker (Elkinton and Wright, 2007). For a blade of 2.5 m width, as for a Fuhrlander turbine of 600 kW output, less than 20% of the sun would be obscured at distances of 3,000 ft or greater.

When the turbine is aligned between the sun and a person, shadow flicker can be an annoyance. Whether flicker is annoying depends on the sharpness of contrast between the light and dark phases of flicker; the duration of the flicker; and the frequency of the flicker (flickers per unit time). Voll (2006) cites a report that light flicker at a frequency above 2.5 Hz can be a disturbance. Rotational frequencies of wind turbines with 80-90 m rotors are, typically, 12 to 20 rpm (translating to 0.6-1.0 Hz). At a maximum rotational speed of 26 rpm, the flicker frequency would be 1.3 Hz, below that identified by Voll (2006) as a disturbance.

Pierpont (2006) speculated that health effects of strobe lighting with respect to imbalance, headaches, and vertigo can arise with wind turbines. A report on the Lincoln, WI 22-turbine wind farm (Bittner-Mackin, 2006) suggests that these effects can occur with wind farms. Their survey indicated that 33% of respondents who live 800-1,300 ft (1/5 to ¼-mile) from the wind farm agreed that "shadows from blades were causing problems in the household." 41% of respondents who lived ¼- to ½-mile away reported problems. Written complaints included balance problems, headaches, and nausea. Bittner-Mackin (2006) noted that drivers may become disoriented by shadow flicker.

Although flickering of light can induce epileptic seizures in people who are photosensitive, shadow flicker from wind turbines is too slow to induce epileptic seizures (Erba, Epilepsy Foundation). About 3-5% of the 1% of Americans who are epileptic are photosensitive. Whether light flicker will provoke a reaction depends on its frequency, light intensity, visual area, image pattern, and color (red is more prone to induce seizures). The flicker frequency that provokes seizures in photosensitive individuals is 5-30 Hz, well above the maximum of 1.3 Hz for wind turbines. Hazardous stimuli for photosensitive people include video games, malfunctioning fluorescent lights, and flashing images on TV.

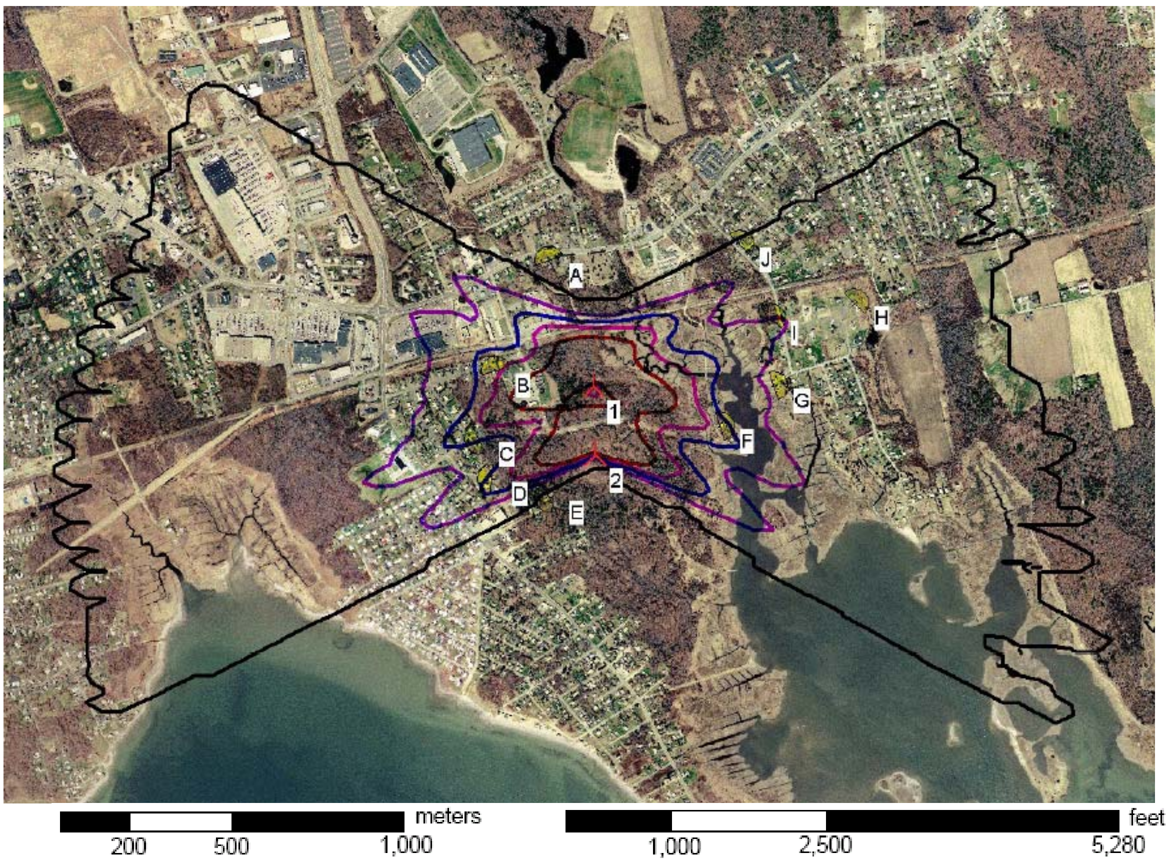
In summary, *shadow flicker from wind farms has been documented to cause annoyance and health effects, and flicker from a single turbine can affect drivers. Flicker from wind turbines is too slow to cause epileptic seizures. FAA lighting requirements should be met so as to control effects at ground level.*

Zones Affected by Shadow Flicker

The incidence of shadow flicker depends on the factors described at the beginning of this section. Generally, the amount of flicker that an area will experience is expressed in terms of the *number of hours per year* that flicker occurs. Given the latitude and siting, this can be calculated from the geometry of the sun, landscape, and other factors. A professional computer program called WindPro (http://www.emd.dk/WindPRO/Frontpage) is used in the industry and has as inputs:

- The latitude and longitude of the turbine
- Locations of receptors, i.e. houses, schools, or other dwellings
- The topography of the landscape, which can block light or create longer shadows
- The turbine rotor diameter
- The turbine hub height
- The random distribution of wind speed and direction, which affect the angular orientation of the turbine relative to the sun
- The hours of sunshine as affected by cloudiness
- The estimated percentage of time the turbine would be rotating

From these inputs, curves surrounding the turbine can be drawn that show the area and the total number of hours per year that flicker will occur. The Renewable Energy Research Laboratory, with support from MassTech, performed this type of analysis for two turbines with a tower height of 80 m and rotor diameter of 77 m proposed for Fairhaven, MA (Elkinton and Wright, 2007). One of their images is reproduced below:



Estimated lines of constant shadow flicker in total hours per year at Fairhaven, MA for two turbines (1 and 2 above); lines depict number of hours of flicker per year

0 10 20 30 50

The closest dwelling, labeled B above, was calculated to experience a total of 31 hours and 13 minutes of shadow flicker over the year; this residence is about 800 ft west-northwest of turbine 1. Residence F would experience 30:35 hr, D 28:29 hr, and C 23:39 hr. These numbers are affected by percentage of days that are sunny, which for Fairhaven range from 49% in November to 62% in July.

A free tool for plotting flicker areas is available from the Danish Wind Industry Association at http://www.windpower.org/en/tour/env/shadow/shadowc.htm. Inputs to this tool include latitude and longitude, time zone, turbine hub height and rotor diameter, percentage of days that are sunny, and percentage of time the turbine is running. No adjustment is made for land topography. Calculations for Barrington using this tool are presented in the next subsection.

A commonly used limit for allowable flicker is 30 hours per year (Elkinton and Wright, 2007). In Sweden, an additional limit of no more than 30 minutes/day is imposed (Bolton, 2007). This is considered to be of "moderate impact," although it should be noted that the times of day in which flicker occurs are either the early morning or late afternoon, when people are more likely to be home.

Examples of professionally prepared flicker analyses for wind projects are available for Fairhaven, MA (Elkinton and Wright, 2007); Oberon, New South Wales, Australia (Voll, 2006); and Cohocton, NY (Nielsen, 2007; Bolton, 2007).

In summary, *shadow flicker depends on alignment of receiver, sun, and turbine; wind and solar conditions; distance from the turbine; time of day; and time of year. A commonly used limit for acceptable exposure is 30 hours per year.*

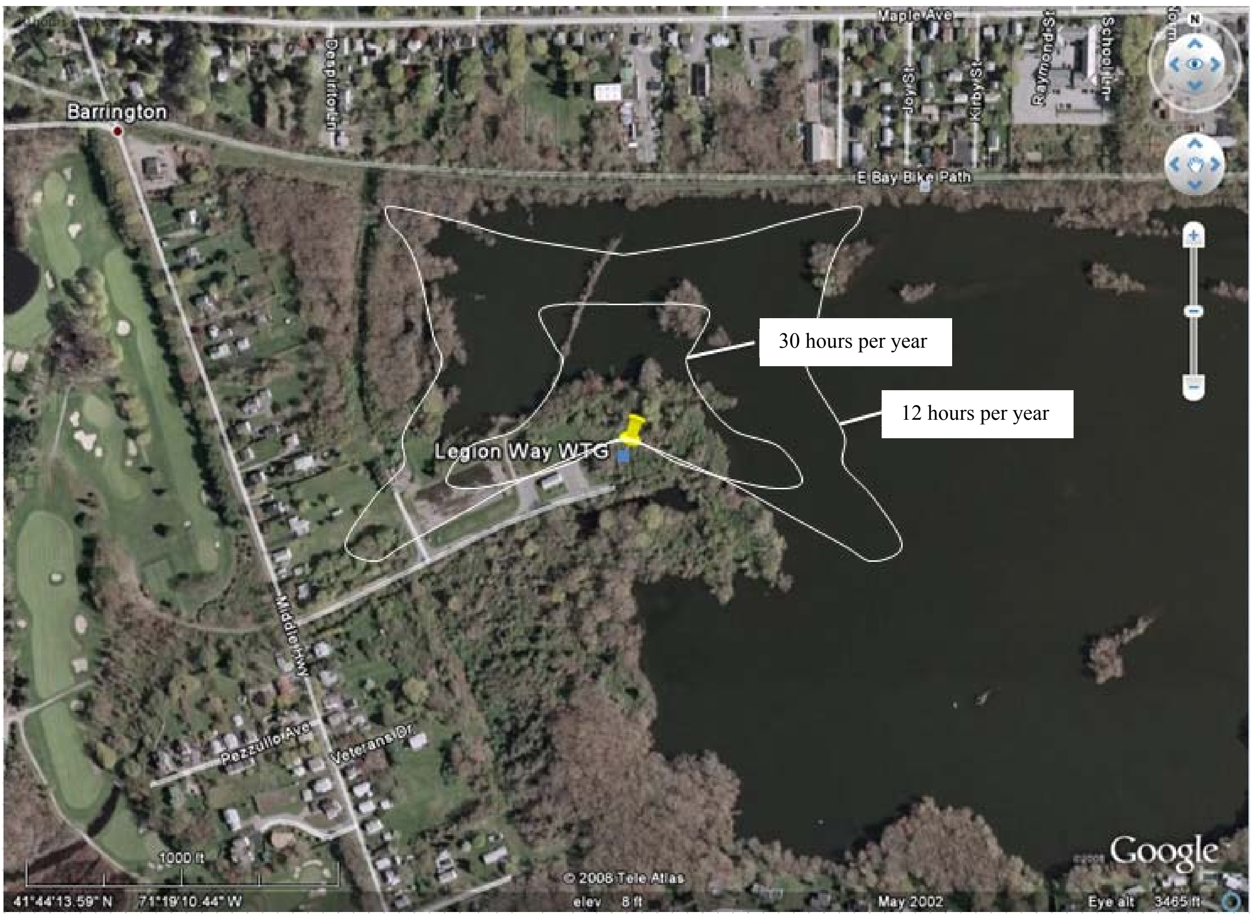
Shadow Flicker at the Barrington High School and Legion Way Sites

It is instructive to use the above information to assess shadow flicker at the two sites in Barrington.

At the High School site, County Road is less than 500 ft from the proposed turbine location. Significant shadow flicker on County Road would occur in the hour or so before sunset. The shadow strength would be very strong given that even blade sections near the tip would obscure 80% or more of the sun, but flicker would only occur on sunny days when the turbine is rotating and is oriented in certain directions. People living at or driving by the corner of Federal Road and Upland Way would experience some flicker for less than 20 minutes in the mornings in winter. Houses and cars at the White Church intersection would be likely to experience flicker in the late afternoon before sunset in winter.

At the Legion Way site, the turbine shadow would reach approximately 15 houses along Middle Highway between the East Bay Bike Path and the Legion Way turnoff for 20 minutes per day for a period of about a month, about one hour after sunrise. This would occur at or near the winter solstice. These houses are all between 1,000 and 1,600 ft from the turbine site. Houses across from Echo Pond are over 3,000 ft away and would therefore not experience noticeable flicker (less than 20% of sun obscured). Many of these houses are surrounded by trees as well. Houses just north of the bike path along Brickyard Pond are 1,200-1,400 ft from the turbine site. These houses are not likely to experience flicker because the sun at midday is always higher than 25 degrees, and at that angle the shadow of the proposed turbine would extend no more than 900 ft from the turbine. The baseball diamond at the YMCA is approximately 3,000 feet from the site. The nacelle of the turbine would not be visible from the baseball field, although the upper blade would be visible. As noted earlier, the turbine at that distance would obscure less than 20% of the sun and would therefore not produce noticeable flicker.

One of the members of CREB, Peter Clifford, used the Danish Wind Industry Association tool (http://www.windpower.org/en/tour/env/shadow/shadowc.htm) to generate hours of flicker per year at different distances from the proposed wind turbine at the Legion Way site. Inputs to the tool were latitude 41°44' north, longitude 71°19' west, time zone 75° meridian, hub height 75 m, rotor diameter 50 m, percentage of days that are sunny 57.5% (for Providence), percentage of time the turbine is operating 80%, and direction the turbine is facing is random. The plot parameters were a 1-year duration with an 8-minute time step, an area of 600 by 600 pixels, and a resolution of 15 m per 15 pixels. Although the tool does not account for topography or screening by trees or buildings, the flat area of Barrington makes topography a minor factor, and obstructions would only lessen the effect. The results of the tool were then superimposed on an aerial photo of the Legion Way site (see below). As can be seen, none of the houses in any direction would experience shadow flicker of even 12 hours per year, much less than the limit of 30 hours per year.



In summary, *at the Barrington High School site, cars and a few houses on County Road, Federal Road, and Upland Way would be likely to experience substantial flicker for less than 20 minutes per day for about one month a year. This would occur only on sunny days when the turbine is operating and is oriented in particular directions. At the Legion Way site, houses along Middle Highway would be exposed to flicker in the early mornings, but the exposure is estimated to be less than 12 hours per year and less than 20 minutes per day.*

Prevention and Control

Setbacks between a turbine and a receiver are one method of avoiding shadow flicker. Setbacks to avoid flicker depend on location relative to the turbine and turbine height. Given that the east and west directions have the longest shadows, setbacks to avoid flicker are longer in those directions. One rule of thumb used by wind consultants is a setback of 10 rotor diameters in the affected directions (Bolton, 2007; Ove Arup and Partners, 2004). For the proposed Barrington turbine, this distance is 500 m, or 1,640 ft, east and west of the turbine.

Another control strategy is to plant evergreen screening vegetation such as a row of long, narrow trees near the affected buildings. The vegetation would need to be of a height similar to the affected buildings and would obviously have to obstruct the line of sight between the buildings and the turbine (Allen, 2006; Voll, 2006).

In summary, *the effects of shadow flicker can be ameliorated through control strategies such as evergreen tree plantings.*

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WILDLIFE IMPACTS

Introduction

Wind turbines can adversely impact wildlife. Impacts can be *direct*, through wildlife mortality from collision with turbines and associated structures (such as meteorological towers); or *indirect*, through habitat disruption or loss from wind turbine construction and maintenance, or behavioral, feeding, or breeding changes that occur due to noise, vibration, or the mere presence of turbines.

Wind farms have been demonstrated to impact birds and bats, but the impacts vary from facility to facility and by region and wildlife species. The impact of a particular wind farm on wildlife depends on site-specific factors, such as topography, the types and densities of wildlife species present, and the type and number of wind turbines installed. This site-specificity makes it difficult to extrapolate the results of a study from one location to another, or to draw conclusions about wind power's impact on wildlife in general.

Impacts on Birds

Many studies have documented the occurrence of bird fatalities associated with wind farms primarily as a result of collisions with turbines. The most well-known of these studies is from the Altamont Pass Wind Resource Area in California, which is associated with the fatality of large numbers of raptors (primarily hawks, kestrels, and eagles) with estimates greater than 1,000 raptors per year (GAO, 2005; NWCC, 2004). Wind energy facilities in other parts of the country have been associated with lower levels of bird mortality, although most facilities have killed at least some birds. It is believed that the unique features of Altamont Pass are the cause of the high mortality rates, including the extremely high number of turbines (over 5,000), the age and size of the turbines (many built in the 1980s, which are shorter than contemporary wind turbines and have rotor blades closer to the ground), and the location of the facility on ridge tops and in canyons where raptors are plentiful (GAO, 2005).

Because of the increase in construction of wind farms, additional studies have been conducted throughout the U.S. to evaluate the relationship between wind farms and bird mortality. Fatality rates of birds vary among sites and likely depend on several factors, such as the turbine location relative to key habitat resources and bird migration pathways, habitat type, and turbine height and design. Most fatality estimates are extrapolated from observed fatalities and are then corrected for observer detection (inefficiencies due to the frequency or size and type of search area), scavenging (loss of carcasses), and other sampling biases (NWCC, 2004).

A recent National Research Council report compiled the results of bird fatality studies conducted at onshore wind farms (NRC, 2007). This information is summarized in the table below. Regional differences in fatality rates are evident in these data, with raptor fatalities higher in the Pacific Northwest and Rocky Mountains and lower in the East and Midwest. However, total bird mortalities show lower rates in the Pacific Northwest and Rocky Mountains and higher rates in the East and Midwest.

Region	Raptor fatalities per turbine per year	All bird fatalities per turbine per year
East	0.03	4.27
Pacific Northwest	0.05	1.98
Rocky Mountains	0.03	1.50
Upper Midwest	0.00	2.22

As compiled by the NRC (2007), 74% of bird fatalities observed in all regions were passerines (a large taxonomic group composed of perching and songbirds); 11% were game birds; 6% were raptors and vultures; and the remaining fatalities (3% and less) occurred to water birds, waterfowl, shorebirds, doves/pigeons, rails/coots, and "other" or unidentified birds. In studies conducted at wind turbine facilities in the eastern U.S. (from one facility in Tennessee and one in West Virginia), about 81% of fatalities were passerines, 6% were "other" birds, and 3% or less were other categories of birds. In a review of bird collisions reported in studies at five wind farms in the Pacific Northwest, Upper Midwest, and Rocky Mountain regions, Erickson et al. (2001) reported that 78% of 192 documented avian fatalities were protected passerines (i.e., protected by the Migratory Bird Treaty Reform Act of 2005)[7].

Leading causes of bird mortality in the U.S., as compiled by the U.S. Fish and Wildlife Service, are presented below for comparison purposes (NRC 2007):

Cause	Bird Fatalities per Year
Building collisions	97 million to 976 million
High tension wire collisions	> 130 million
Communication tower collisions	4 million to 50 million
Motor vehicle collisions	80 million
Pesticide poisoning	> 72 million
Domestic and feral cat attacks	> 100 million
Wind turbine collisions	20,000 to 37,000 (in 2003)

The number of birds killed by wind turbines is much lower than by these other sources, but the number of deaths due to turbines will grow as the number of turbines increases. In 2003, wind turbines generated about 1% of the nation's electric power; were this to rise to 20%, the number of bird fatalities would presumably rise to about 400,000-740,000. Note also that these data do not show whether wind turbine collisions have important local impacts, such as affecting a large percentage of a population of certain regional species.

While the information presented in this summary is somewhat useful in describing the risk of bird fatalities from wind turbines, none of the studies reviewed was from the northeastern U.S. (the studies from the East were in Tennessee and West Virginia), and none was located in coastal areas such as Barrington.

[7] Includes various swallows, warblers, wrens, flycatchers, pipits, robins, goldfinch, larks, blackbirds, bluebirds, towhees, juncos, and others; excluding house sparrows and starlings.

In summary, *based on studies conducted in Tennessee and West Virginia at wind farms, bird mortality in the eastern U.S. averaged about 4 birds per turbine per year. However, any individual site could differ substantially from this number.*

Impacts on Bats

Bat fatalities from wind turbine collisions have been identified in the U.S. and internationally (Arnett et al., 2008). Because wind turbine collision studies were often designed to estimate bird mortality only, estimates of bat mortality are less precise (GAO, 2005). Knowledge of factors associated with bat fatality from wind turbines is limited due to the paucity of well-designed studies as well as limited knowledge of the migratory behaviors of bats (Arnett et al., 2008).

Early studies identified higher bat fatality rates at wind farms in the eastern U.S. than in western states (NRC, 2007). Studies in West Virginia and Pennsylvania found over 2,000 bats killed during a 7-month period and a 6-week period, respectively (GAO, 2005). A study of a 3-turbine wind facility on a forested ridge in Tennessee estimated a fatality rate of about 21 bats per turbine per year (GAO, 2005). These early studies identified forested ridges in the eastern U.S. as exceptionally high-risk sites for bat fatalities.

The NRC (2007) report compiled the results of 11 bat fatality studies conducted at land-based wind farms of between 3 and 454 turbines, summarized in the table below. Bat fatalities were highest in the East, where all of the facilities were on deciduous forested ridges, and lowest in the Upper Midwest, where the facilities were located on cropland or grassland. Arnett et al. (2008) cited an additional study from Maple Ridge, NY, with an estimated mean bat fatality of 24.5 bats per turbine per year.

Region	**Bat fatalities per turbine per year**	**Bat fatalities per MW per year**
East	21-48	15.3-41.1
Pacific Northwest	0.7-3.1	0.8-2.5
Rocky Mountains	--	2
South Central	--	0.8
Upper Midwest	0.2-7.7	0.8-8.6

A large percentage of bat mortality has been found to occur during the late summer/early fall migration season (NWCC, 2004; Arnett et al., 2008). Of the 45 bat species that occur north of Mexico, 11 species have been recovered in ground searches at wind energy facilities (Arnett et al., 2008). Among these, nearly 75% have been eastern red bats, hoary bats, and silver-haired bats, each of which migrate long distances (Arnett et al., 2008).

Similar to bird fatalities, none of the identified studies was from the northeastern U.S. and none was located in coastal areas such as Barrington.

In summary, *bat mortality at wind farms appears to be higher than bird mortality and, in the eastern U.S., averaged 21-48 bat fatalities per turbine per year. However, any individual site could differ substantially from this number.*

Wildlife Evaluations

Guidelines to evaluate the suitability and monitor the potential adverse environmental effects of specific wind turbine projects have been developed by some states, federal governments outside the U.S., and non-regulatory groups (Environment Canada, 2006; Washington Department of Fish and Wildlife, 2003; Pennsylvania Game Commission, 2007; New York State Department of Environmental Conservation, 2007; Clean Energy States Alliance, 2006). Common components of these guidelines include:

- Pre-development assessments:
  - Gathering of existing baseline information on the use and habitat of the proposed turbine location.
  - Habitat survey to identify the presence of state or federally-listed rare, threatened, or endangered species or species of special concern.
  - Avian use surveys, including breeding bird and waterfowl surveys and raptor and songbird migration surveys.
  - Bat use surveys, including hibernacula, migrating, and bat acoustical surveys.
- Post-construction monitoring for bird and bat mortality (e.g. carcass searches and collision studies) and for changes in bird and bat use or presence within the habitat.
- Mitigation measures ("adaptive management") as needed.

In summary, *various governmental organizations recommend wildlife evaluations that include pre-development use and habitat surveys, post-construction monitoring, and mitigation measures as needed.*

Wind Turbine Siting Recommendations

The U.S. Fish and Wildlife Service has been designated the lead governmental agency for developing guidelines and recommendations addressing potential wildlife impacts from the siting of wind turbines (GAO, 2005). Interim guidelines, which are strictly voluntary, contain the following site development recommendations (condensed below) (FWS, 2003):

- Avoid placing turbines in documented locations of any species of wildlife, fish, or plant protected under the Federal Endangered Species Act.
- Avoid placing turbines in known bird migration pathways or in areas where birds are highly concentrated, such as wetlands, state or federal refuges, or riparian areas along streams, unless mortality risk is low (birds present rarely enter the rotor-swept area).
- Avoid placing turbines in areas with a high incidence of fog, mist, low cloud ceilings, and low visibility.
- Avoid placing turbines in or near known bat hibernation or breeding locations, maternity/nursing colonies, migration corridors, or flight paths between colonies and feeding areas.

- Configure turbine locations to avoid areas or features known to attract raptors (cliff/rim edges, dips or passes in a ridge).
- Avoid fragmenting large, contiguous tracts of wildlife habitat.
- Minimize roads, fences, and other infrastructure.
- Develop a habitat restoration plan that avoids or minimizes negative impacts on vulnerable wildlife while maintaining or enhancing habitat values for other species.
- Reduce availability of carrion by practicing responsible animal husbandry (e.g., removing carcasses) to avoid attracting raptors.

The FWS (2003) guidelines also suggest some turbine design and operation considerations (abbreviated):

- Use tubular supports with pointed tops that discourage roosting or nesting.
- If FAA warning lights are required, use white rather than red lights, which appear to attract night-migrating birds.
- Adjust tower height where feasible to reduce risk of strikes.
- If feasible, place power lines underground to avoid bird electrocution.
- Collect ~3 years of monitoring data to determine peak bird concentration periods.

In summary, *the U.S. Fish and Wildlife Service recommends avoiding placement of turbines or turbine arrays in known areas of high bird or bat concentrations. Turbine design and operation recommendations include discouraging roosting or nesting, adjusting FAA warning lights, and collecting ~3 years of monitoring data.*

Wildlife Impacts References

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